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Neural Network Controller Application on a Visual based Object Tracking and Following Robot

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ABSTRACT

Navigation is the main issue for autonomous mobile robot due to its mobility in an unstructured environment. The autonomous object tracking and following robot has been applied in many places such as transport robot in industry and hospital, and as an entertainment robot. This kind of image processing based navigation requires more re-sources for computational time, however microcontroller currently applied to a robot has limited memory. Therefore, effective image processing from a vision sensor and obstacle avoidances from distance sensors need to be processed efficiently. The ap-plication of neural network can be an alternative to get a faster trajectory generation. This paper proposes a simple image processing and combines image processing result with distance information to the obstacles from distance sensors. The combination is conducted by the neural network to get the effective control input for robot motion in navigating through its assigned environment. The robot is deployed in three different environmental setting to show the effectiveness of the proposed method. The exper-imental results show that the robot can navigate itself effectively within reasonable time periods.

Keywords: Image Processing, Neural Network, Object Following Robot, Tracking Robot, Vision-based Control.

1. INTRODUCTION

Navigation is an important issue for mobile robot due to its mobility in an unstructured or unknown environment [1]. One of the navigation methods is by tracking and following an object. The object-tracking-and-following robot is applied in many places, such as a domestic application for games such as soccer robot, and industry, restaurant [2] and hospital for transport robot [3][4], where a robot is only required to detect and follow a human or another robot without physical attachment [5]-[8].

The navigation task occurs in an object-tracking-and-following robot had been an issue in finding the most effective ways to get the robot smoothly move from starting point to the final one. Vision-based navigation relies on image processing process that requires more memory resources. Therefore it is quite challenging to get an effective trajectory concerning the source needed by the computing time to get the precise detection with image processing. The microcontroller commonly installed on the robot has a limited memory that has to be divided between image processing for object detection and controlling motor to get the right direction and velocity. This division needs to be done due to the limited source. Therefore, the effective and efficient method in image processing is required.

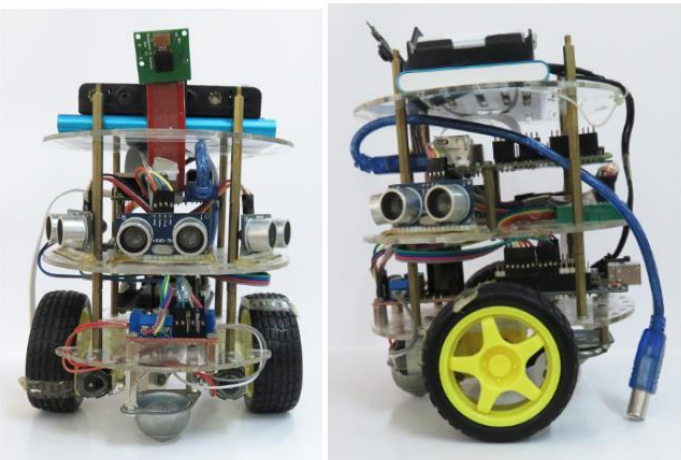
Several control methods had been presented to get an effective and efficient tra-jectory for the robot including the classic control theorem, PID controller. In many cases, the PID controller only is not enough, however, to get a more effective re-sult, researchers combined it with an advanced controller such as adaptive control and artificial intelligence (AI). The most commonly apply controller is the fuzzy logic controller [9]-[11]. Another type of AI is the neural network, which imitates how the human brain works [12]-[18].

Image processing [19] should be kept simple and efficient to avoid unnecessary memory usage. The image processing method can be combined with the neural net-work to obtain an effective trajectory tracking. Trajectory generation as part of mobile robot navigation system can be online or off-line or predefined. The process of trajec-tory generation includes obstacle avoidance and target reaching [20]-[22]. Therefore the combination with AI will enhance the efficiency in target tracking due to robot ability in deciding the best path to get the destination faster due to the installed brain.

This paper proposes the combination of neural network and image processing for object tracking and following robot. The effectiveness of the proposed method is shown by setting the robot is to track and follow a red ball as the target in several environment settings. Image processing method is applied to detect the target, and the processing is kept simple to reduce memory usage. The robot is also equipped with proximity sensors to ensure the smooth trajectory tracking. The inputs from a vision sensor and proximity sensors become the inputs to the neural network, and the output will be utilized by the microcontroller to control robot motion.

2. MOBILE ROBOT DESIGN

The mobile robot considered in this paper is the differential driven mobile robot shown in 1. This type of robot is commonly applied in many applications. The position and orientation is given by $q_r = [x_r, y_r, \phi_r]^T$, where x_r and y_r is the X and Y axis, and ϕ_r is the orientation respect to Z axis.



(a) Right side of robot (b) Left side of robot

FIGURE 1. The designed mobile robot

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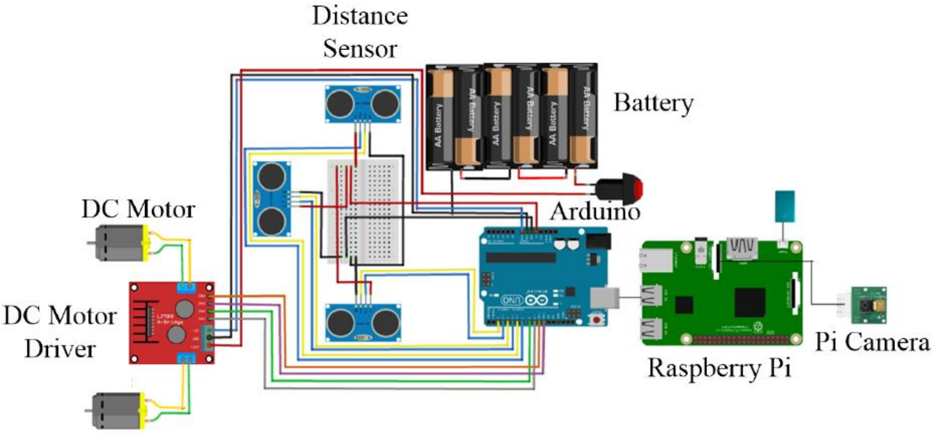

FIGURE 2. Schematic Diagram

The translational velocities derived from the orientation are:

$$v = [v_{m1}, v_{m2}]^T \tag{1}$$

and the angular velocity is given by:

$$\omega = \frac{R}{2L}\left(\dot{\theta}_r - \dot{\theta}_l\right) \tag{2}$$

where v_{m1} and v_{m2} are the left and right motor velocities, $\dot{\theta}_r$ and $\dot{\theta}_l$ are the left and right wheels angular velocities respectively.

The control input applied to the robot is:

$$u = \frac{R}{2}\left(\dot{\theta}_r + \dot{\theta}_l\right) \tag{3}$$

where θ_r and θ_l are the left and right wheels orientation

The robot applied in this research is equipped with three distance sensors (D_{S1}-D_{S3}), and a vision sensor (V_S). The vision sensor installed to the robot is a Pi camera, and image processing for object detection is conducted in the Raspberry Pi. The complete components installed to this robot is shown in Figure 2. The robot in this paper is considered moving only forward without slipping and skidding.

3. IMAGE PROCESSING

Trajectory generation based on object detection relies heavily on image processing. In this paper, image processing is made to be simple and yet effective in detecting thE target. The target considered is a red ball. The raw image captured by

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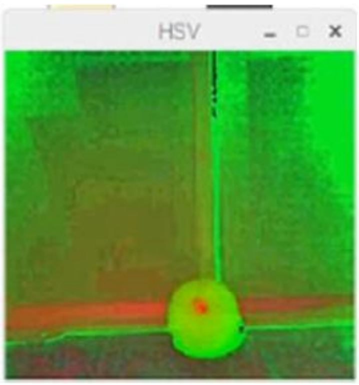
Pi Camera is processed by Raspberry Pi and becomes the input to the neural network controller.

Figure 3b shows the result of HSV process. HSV (hue, saturation, value) is converted from RGB image (original image in fig. 3a). Hue is a measure of the wavelength and saturation is the amount of white light inside hue. HSV separates the image intensity from color information, in this method the ball shape and red image color component can be separated from the background colors.

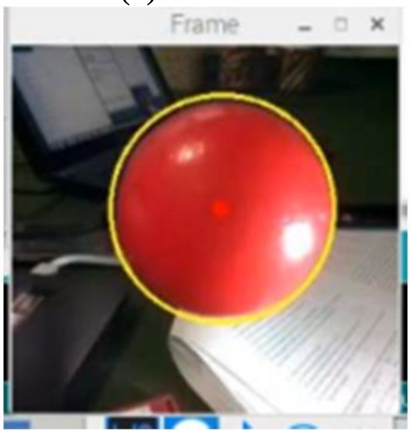
The conversion of RGB to HSV can be represented by

$$R_n = \frac{R}{2^b}, \quad G_n = \frac{G}{2^b}, \quad B_n = \frac{B}{2^b} \qquad (4)$$

where R_n, G_n, and B_n are the normalized of RGB component and b is the bit length of each color component.



(a) Raw Image (b) HSV



(c) Thresholding (d) The detected image

FIGURE 3. The designed mobile robot

The process is continued to Figure 3c by partitioning the raw image into the fore-ground and background. Thresholding isolates the red ball by converting the grayscale images into a binary image, and therefore by analyzing the level of contrast, the red ball is detected as shown in Figure 3d. The yellow box shown in Figure 3d is only for the viewer, to indicate that the target is detected.

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The result of image processing is the coordinate position of the target in x and y −axis. Based on this detected coordinates, the robot can follow the target effectively.

4. NEURAL NETWORK CONTROLLER

The neural network controller is the part of artificial intelligence that mimics the human brain to decide the outputs. In this study, the back-propagation is applied to determine robot motion based on the inputs from a vision sensor and distance sensors attach to the robot. Figure 4 shows the application of a neural network in this study.

The neural network design is including four input layers, three from distance sensors and one from a vision sensor. Five hidden layers are chosen as the most effective ones after trial and error, and the output is control input to the main controller. The control input in this study is the translational and angular velocities.

Distance sensors give the distance information between the robot and the obstacles and the red ball as the target. The left and right distance sensors are utilized mainly for obstacle avoidance, and the front distance sensor is for keeping the safe distance with the target. As the vision sensor detects the target, the robot will move to follow it at a certain distance, and this condition is updated online provided by the neural network controller. The obstacles detection also affect the robot velocity and orientation, when the robot is approaching the target or obstacles, the controller will reduce the PWM signal to DC motor driver to slow down the robot, and if the detection by one of the distance sensors, the robot might turn left or right depend on the situation.

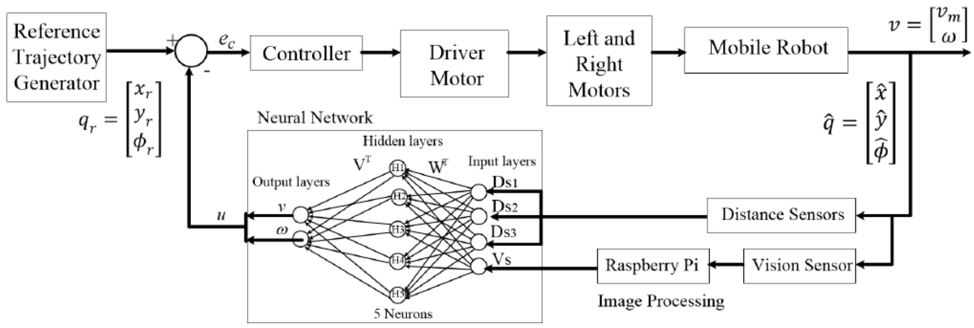

FIGURE 4. Neural network application in this study

5. RESULT AND DISCUSSION

The effectiveness of the proposed method for object detection and tracking robot is proven by deploying the robot in several environments setting. The robot is set to follow the target (red ball) from initial position to final position and avoiding obstacles without losing the sight of the target.

The robot is controlled by Arduino Uno which includes ATMega micro-controller connected to 2 DC motor driver L298N for 2 DC motors. The power supply is pro-vided by 1900 mAH battery to power DC motor driver, DC motor, distance sensors, and Arduino UNO. A powerbank is also included to power Raspberry Pi responsible for image processing. The robot weight is 0.5 kg, height 20cm, and diameter 14.5 cm.

The detected image in the image plane gives the x and y coordinates. The image plane is set to be in 256 240 pixel and based on that pixel setting. The x coordinate range is 0 - 256, and the y coordinate range is 0 - 240. The pixel setting is based on trial and error, the higher the resolution, the more memory resource needed, and the slower the process is. The robot moves based on the target and obstacle detection. The x and y coordinate position of the target is the input for robot direction and orientation, as shown in Table 1.

Figure 5 shows robot motion in the environment setting 1. This setting does not include many obstacle avoidances only at the beginning and when the robot reaches the final position. Figure 6 is similar with igure 5, the difference is on the obstacle avoidance in Figure 6b and 6e. Figure 7 shows robot motion in environmental setting 3, in this setting, the robot is deliberately set to encounter obstacles, and the robot successfully follows the target and reach final position without crushing to any obstacles. Table 2 shows the times require for the robot to finish its task in 3 environmental settings.

TABLE 1.

Target position in image plane and robot motion relationship

Target x-axis Coordinate	Right motor	Left motor	Robot Motion
0 - 90	1 (High)	0 (Low)	Turn left
100 - 170	1	1	Forward
175 - 257	0	1	Turn right

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(a) Initial position

(b) Robot detects and follows target, and at the same time avoids an obstacle

(c) Straight motion

(d) Straight motion

(e) Straight motion

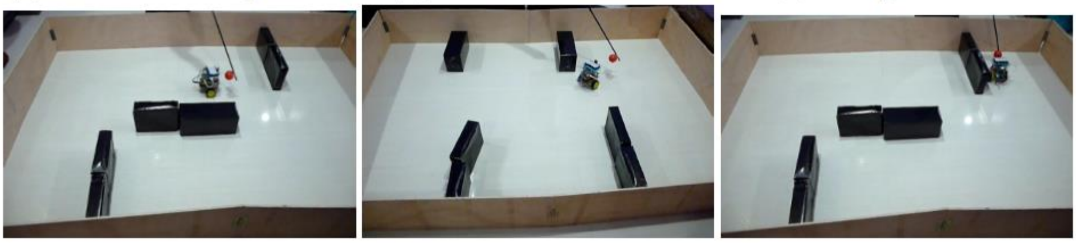
(f) Robot reaches the final Position

FIGURE 5. Robot motion in environment setting 1

(a) Robot in initial position

(b) Obstacle avoidance

(c) Straight motion



(d) Straight motion

(e) Straight motion

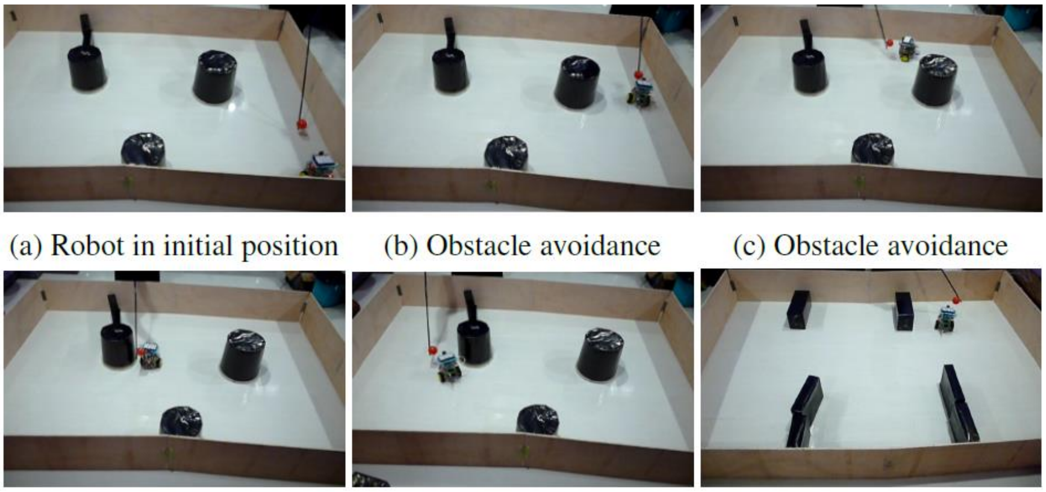
(f) Obstacle avoidance

FIGURE 6. Robot in environment setting 2

TABLE 2.

Time requires to reach final position in 3 environments setting

Environment Setting No.	Number of Trial (in second)				
	1	2	3	4	5
1	38.81	36.06	30.48	30.94	29.23
2	34.90	52.96	43.28	37.27	53.38
3	44.35	59.11	45.09	60.01	49.05



(a) Robot in initial position (b) Obstacle avoidance (c) Obstacle avoidance

(d) Obstacle avoidance (e) Obstacle avoidance (f) Final position

FIGURE 7. Robot motion in environment 3

6. CONCLUSION

This paper presents the application of a neural network controller for a vision based object tracking and following robot. There are two types of sensors installed in this robot, distance sensors, and a vision sensor. Sensors output becomes the input for the neural network, and its output is the input to the main controller to control robot motion. The robot is applied in three environmental settings to show the effectiveness of the proposed method, and the robot can finish all the assigned tasks in reasonable time periods.

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